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LIFE EXPECTANCY OF STEAM PLANT EQUIPMENT

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LIFE EXPECTANCY OF STEAM PLANT EQUIPMENT

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In order that there will be no misunderstanding of my position, I should like to state at the outset that anyone who attempts to make an accurate estimate of the life expectancy of a modern steam power plant or any of its major components, immediately finds himself in the realm of pure conjecture.

However, there are many public utility engineers who must make such estimates today. Rate cases before regulatory commissions involving estimates of property values, depreciation accounting systems and economic comparisons of alternate sources of electric power—all these require an accurate estimate of life expectancy.

Since a definitive solution of the problem must be reached, the engineer has to depend on his judgment for the ultimate answer. He has Patrick Henry's lamp of experience to guide his feet. If we combine this lamp of experience with the laws of probability we have the science of statistical analysis and that is one of the modern tools that the engineer has at his disposal to help him formulate his judgment in matters of this kind.

It might be worth while to disgress from the specific subject of this paper and to discuss the broad application of statistical analysis as an aid in estimating the average life expectancy of utility property in general. I shall return to the specific application of statistical analysis after I have described the historical development of the methods used. Many of the following remarks appeared in my paper presented in Chicago in April 1953 at the National Conference of Electric and Gas Utility Accountants.[2] They are summarized here because they may be of interest to engineers not directly associated with the public utility business.

There are two general classes of probability which are known as Mathematical Probability and Statistical Probability. The first class is susceptible to a quantitative analysis which is predeterminable because one or more of the natural laws of probability is involved. The other class of probability involves a combination of physical, economical and sociological variables which present problems that cannot be solved by mathematics alone, but by the joint use of mathematics and statistical experience. The estimation of human life expectation and physical property life expectation fall within statistical probability.

The solution of problems involving statistical probability generally depend on the use of actuarial methods of life analysis.

The application of these methods to a utility company's experience generally involves the statistical procedure known as the "annual rate method" of analysis. This procedure relates the survivors of a given age in a particular property account to the survivors of the previous age-year, thus yielding a sequence of annual survival probabilities from which a survivorship characteristic can be constructed. This survivorship characteristic if plotted on

1. Chf. Appraisal Engr., Ebasco Services Inc., New York, N. Y.
2. "Application of Actuarial Analysis to Depreciation Accounting for Public Utilities."

graph paper forms what is known as a survivor, or mortality curve. The length of this curve depends primarily upon the years of experience available. Hence, if the experience band of years is short in relation to the average life of the property, an incomplete or stub survivor curve results. There are a number of acceptable actuarial methods of smoothing and projecting this stub survivor curve in order to compute the area under it from which the average life is determined.

Actuarial analysis was not used in the industrial field until after 1900. Its serious application to the utility field was first mentioned in a paper published in March, 1913 by the American Electric Railway Association. Its author was Edwin Gruhl, who at that time was Assistant to the President of the Milwaukee Electric Railway and Light Company.

Another milestone along the road to the goal advocated by Gruhl was testimony presented before the Interstate Commerce Commission in Washington in March, 1928 by the American Telephone and Telegraph Company in connection with depreciation charges of telephone companies in which is described the method used in determining such depreciation charges. Under this method a stub or complete survivor curve is developed from actual experience by the annual rate method and smoothed and extended by the Gompertz-Makeham formula. The Gompertz-Makeham law of mortality is the result of the Gompertz's work in 1825 and Makeham's modification in 1860. The law follows from the assumption that death is a consequence of two coexisting causes, the one, chance, without previous disposition to death or deterioration; the other, a deterioration, or increased inability to withstand destruction. The intensity of mortality resulting from the first cause is constant and from the second an increasing geometrical progression. A discussion of the application of this law to the physical property in the telephone industry was covered in a paper by Allan B. Crunden and Donald R. Belcher entitled "The Straight-Line Depreciation Accounting Practice of Telephone Companies in the United States" and published in Volume 8 of the Bell Telephone Quarterly for the year 1929.

A most important contribution to the practical application of actuarial theory to industrial property was made by Robley Winfrey and his associates at the Iowa Engineering Experiment Station. The results of his studies were published in 1935 in Bulletin 125 entitled "Statistical Analysis of Industrial Property Retirements." Professor Winfrey's procedure of matching a stub survivor curve to one of his 18 type curves was a practical solution to a problem that previously had required the use of complicated mathematical procedures. It is assumed under this procedure that the stub curve will have the same mortality characteristics as the type curve selected. The selection of the appropriate type curve and average life is accomplished by plotting the stub curve on rectangular coordinate paper and superimposing it on Iowa curves of the various types and average lives drawn to the same scale, and then determining by judgment which curve type best suits the stub.

Much credit is due to Professor Edwin B. Kurtz for his fine pioneering work, extending back to 1916, in the application of actuarial analysis to industrial property. His textbook entitled "Life Expectancy of Physical Property" published in 1930 was a valuable contribution to the literature, as was his later book "The Science of Valuation and Depreciation," published in 1937. His work in collaboration with Winfrey, which was published in 1931 by the Iowa Engineering Experiment Station under Bulletin 103 "Life Characteristics of Physical Property," formed the groundwork upon which the 18 type curves of the Iowa system were based.

A third actuarial method was developed which involved the smoothing and extending of the observed retirement ratios by the principle of least squares. An important simplification of the mathematical calculations required under this method was accomplished in 1937 by C. Beverley Benson, Consulting Engineer for the New York Public Service Commission, by the introduction of procedures based upon Professor R. A. Fisher's adaptation of orthogonal polynomials. Fisher, a Cambridge University Professor, published his findings in a work entitled "Statistical Methods for Research Workers." This work was first published in 1925 and has had its latest reprinting in 1950.

Other actuarial procedures have been developed but they are primarily variations of the three main methods mentioned, or they have limited application to industrial property.

Summing up, the three basic actuarial methods for making statistical analyses of mortality data may be described as follows:

I. The Observed Life Table Method.

This method consists of smoothing and extending the observed survivor percentages by the Gompertz-Makeham formula or some modification thereof. This method is the one most used by life insurance actuaries and is also favored by the Bell telephone system companies. The main criticism of its use when applied to utility property is that it is based upon human mortality and does not make sufficient allowance for obsolescence. The modification made by the Bell telephone system companies is supposed to have corrected for this criticism of the basic formula.

II. Frequency Table Method.

This method depends upon smoothing and extending the frequencies of the retirements by a mathematical equation. This was the method used for smoothing the 18 type frequency curves and their corresponding survivor curves developed by Professor Winfrey and his associates. The important by-product of this method is the graphic curve fitting procedure involving the use of the 18 type curves.

III. The Retirement Ratios Method.

This method, like the first, is a mathematical one and depends upon smoothing and projecting the retirement ratios by either least squares or Professor Fisher's mathematical procedure.

For a critical comparison of these methods I refer you to the 1952 Report of the Engineering Subcommittee of the EEI Depreciation Accounting Committee entitled "Methods of Estimating Utility Plant Life."

As far as I could learn there has been little, if any, application of the first method to the electric and gas utility industries. The frequency Table Method, especially the Iowa system, has met with wider acceptance in both industries than the Retirement Ratios Method. Both have advantages. Some of the practical advantages claimed for the Iowa type curves are:

1) They were developed from actual mortality experience relating to industrial property;
2) They form a standard of comparison whereby the mortality experience of one utility may be compared directly with that of another for similar equipment;

3) They make possible the practical solution of laborious mathematical calculations by means of graphs and tables prepared for a wide range of average life and type curve combinations;
4) The graphic solution provided by the Iowa type curve system is as accurate for practical purposes as the results of the other two mathematical methods.
5) In property accounts where there is not sufficient experience to make a graphic fit, a type curve may be selected on the basis of judgment;
6) After the type curve is selected, tables are available to provide the per cent of accrued depreciation for each vintage of surviving dollars in an account.

Advocates claim the following advantages for the Retirement Ratios Method using Fisher's mathematical procedures:

1) Retirement ratios for a number of age intervals are independent of each other, hence the retirement ratios at one age need not necessarily influence those at other ages.
2) No fundamental law of mortality need be assumed beyond the elementary one that the older the property is, the more likely it is to be retired;
3) The mathematical procedures are simplified because experience has shown that a simple type of equation can be used to describe the retirement ratio curve, and therefore the data can be allowed to dictate the form of this equation;
4) The mathematical solution is further simplified by the use of the Fisher procedure, because, if a first degree curve does not give a good fit, a second or higher degree equation may be calculated without doing the work over as is necessary in the ordinary least squares computations;
5) Permits a more accurate evaluation of the series of observed data to determine which portion of the series conforms with the elementary law of mortality (mentioned under item 2 above) and which should be included in the calculations.

I should now like to comment on the application of these methods to the major classes of steam plant equipment: boilers and turbo-generators. Since many electric operating companies have not experienced any retirements of the larger sizes of boilers and turbo-generators, it was thought that a statistical analysis of the retirement experience of a large sample of the industry would be a helpful guide and an aid in estimating the probable life expectancy for these classes of power plant equipment.

Ebasco Services Incorporated has completed mortality studies covering a representative sample of the larger sizes of steam boilers and turbo-generators in central station use. The mortality studies were based on the experience of 24 electric utilities for boilers having a rating 50,000 pounds of steam per hour and above and for turbo-generators having a nameplate rating of 10,000 kw and above. Annual rate actuarial studies were made for an experience band of years 1920 to 1951, inclusive. The vintage band for boilers was 1900-1951, inclusive, and for turbo-generators 1906-1951, inclusive.

The sample included in the turbo-generator study comprised approximately 35% of the total installed capacity in the privately owned electric utilities in the United States at December 31, 1951. The total capacity of turbo-generators in service at that date in privately owned electric utilities was 49,797,000 kw

of which only 1,120,000 kw were below 10,000 kw capacity. It is also estimated that the boiler data analyzed represent a similar sized sample. The following indicates the over-all size of the sample used:

	Boilers		Turbo-Generators	
	Units	M lbs/hr	Units	M kw
Exposed	812	220,712	429	17,898
Retired	122	22,555	27	563
In Service at December 31, 1951	690	198,157	402	17,335

For the purpose of comparison, annual rate analyses were made on a unit basis and also on a basis giving weight to the rating of the equipment. The results of the annual rate analyses were converted into estimates of average life by the use of the Iowa Type Curve System (Frequency Table Method), a graphic solution, and the Retirement Ratios Method, a mathematical solution. The Fisher mathematical procedures were used in the latter method to replace the more tedious least square computations.

Using the first of these methods, Iowa type curves were graphically fitted to the plotted experience data of the reporting companies and the average life selected was to the nearest five years of average life without any attempt to interpolate between curve types or five year steps of average life. As shown on the two charts following, this method indicates that the R_3 type curve and 40 years average life for boilers and an R_2 type curve and 60 years average life for turbo-generators are the curves of best average fit for the mortality experience analyzed.

The Retirement Ratios Method indicates a range of average life, depending on the weighting used, of between 34 and 41 years for boilers and between 42 and 54 years for turbo-generators.

It seems fairly conclusive that insofar as boilers are concerned the average service life based on past experience ranges from 35 to 40 years. With the experience band used in the study (1920-1951 inclusive) maximum retirements came to 50 per cent on a unit basis and about 75 per cent on a rating basis. This produced a stub curve of sufficient length to give conclusive results.

However, in the case of turbo-generators using the same experience band as for boilers, the maximum retirements attained values of only 17 and 11 per cent respectively. With such small percentages of total experienced retirements the resulting stub curve may not be of sufficient length to indicate a conclusive trend. The indicated results of both methods show that the probable average service life for turbo-generators ranges between 45 and 60 years.

It is also too early to evaluate the extent to which the difference in engineering characteristics of the various vintages of boilers and turbo-generators will affect the future life expectancy of equipment in service today. However, we can predict with some assurance that the practice followed by the industry during the past decade of installing only one boiler to supply each turbo-generator will probably result in a narrowing of the difference in average life expectancy indicated by these studies. On the other hand, the replacement in some existing plants of boilers using conventional fuel with nuclear reactors is a definite possibility in the forseeable future. Such a practice would have substantially the same effect on existing turbo-generator capacity as the installation of topping units in older plants a decade ago. If this practice is followed, it will result in existing boilers having a shorter average life than the turbo-generators that were installed during the same period.

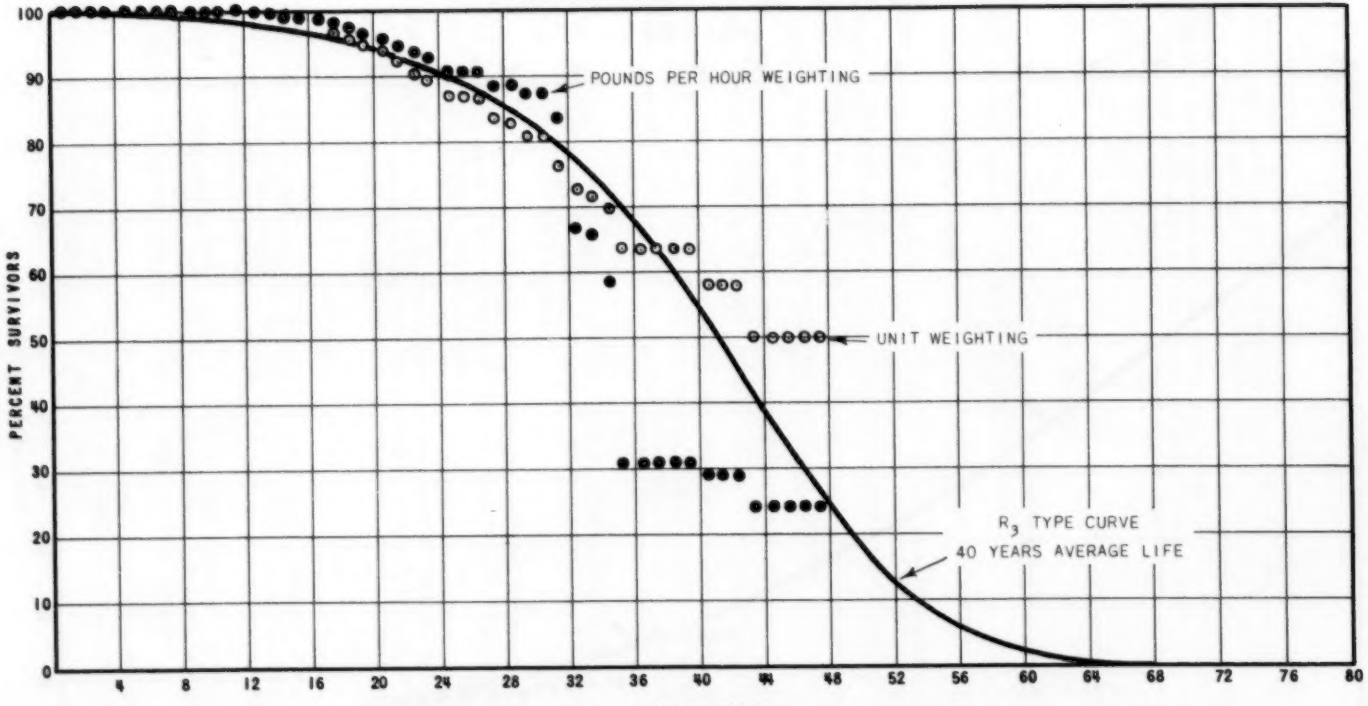
I should like to conclude with a few remarks concerning the prudence of using past experience as a basis for estimating life expectancy of modern steam power plant equipment.

In this connection an excerpt from Bulletin 125 of the Iowa Engineering Experiment Station is particularly appropriate:—

> "While the author strongly recommends the development and use of retirement data and survivor curves as the basis of estimating the probable life of property units, he does not mean to infer that expert judgment should be done away with in favor of pure statistical treatment. Each individual item, each group of items, and each property or company must be dealt with in the light of its present condition, its character and amount of service or production, and its relation to the present and probable future economic trends, art of manufacture and management policies. Tables of probable service lives, type survivor curves, and statistical methods are simply means of recording past experience to use in predicting what the future service might be."

In other words, it should be remembered that the various average service lives presented herein were based on an analysis of past mortality experience and their use should be considered only as a starting point and an aid to judgment. Each company will have its own answers to such questions as the amount of reserve capacity required for its system, the probable imminence of atomic energy for power generation and many other operating problems which would affect the probable average service lives of its own generating equipment in the future.

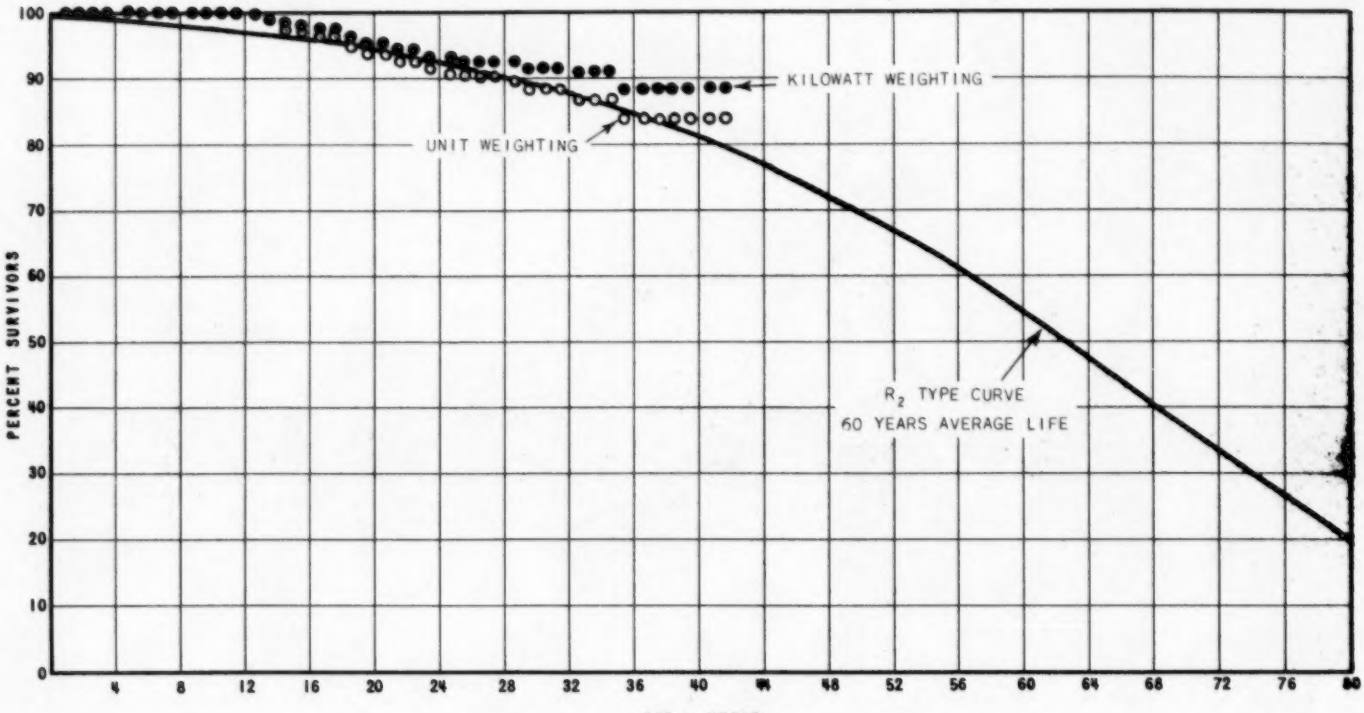
CHART I MORTALITY ANALYSIS BY FREQUENCY TABLE METHOD



WATER TUBE BOILERS - 50 M LB/HR AND LARGER

EXPERIENCE BAND: 1920 - 1951, INCLUSIVE
VINTAGE BAND : 1900 - 1951, INCLUSIVE

CHART II MORTALITY ANALYSIS BY FREQUENCY TABLE METHOD



TURBOGENERATORS - 10 MKW AND LARGER

EXPERIENCE BAND: 1920 - 1951, INCLUSIVE
VINTAGE BAND : 1906 - 1951, INCLUSIVE

PROCEEDINGS-SEPARATES

The technical papers published in the past year are presented below. Technical-division sponsorship is indicated by an abbreviation at the end of each Separate Number, the symbols referring to: Air Transport (AT), City Planning (CP), Construction (CO), Engineering Mechanics (EM), Highway (HW), Hydraulics (HY), Irrigation and Drainage (IR), Power (PO), Sanitary Engineering (SA), Soil Mechanics and Foundations (SM), Structural (ST), Surveying and Mapping (SU), and Waterways (WW) divisions. For titles and order coupons, refer to the appropriate issue of "Civil Engineering" or write for a cumulative price list.

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c. Discussion of several papers, grouped by Divisions.
d. Presented at the Atlanta (Ga.) Convention of the Society in February, 1954.
e. Presented at the Atlantic City (N.J.) Convention in June, 1954.

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